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Sarah Jane Robbins, Student

Heather Bush, PhD, Committee Chair

Dr. Sarah Wackerbarth, Director of Graduate Studies

Rabies in Kentucky from 1989-2020: A case for surveillance

CAPSTONE PROJECT PAPER

A paper submitted in partial fulfillment of the
requirements for the degree of
Master of Public Health
in the
University of Kentucky College of Public Health

By
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Lexington, Kentucky

Lexington, Kentucky
May 14th, 2021

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Motivation

The Kentucky rabies reporting system includes data from five laboratories and provides an account of suspected rabies reports since 1989. Given the multiple sources of data, the reporting system lacks standardization and comprehensive information about suspected rabies events. Currently, the only information retained across all years is species, submission date, laboratory test result, exposure type, and county. Limited data are a direct result of the lack of universal reporting methods by laboratories submitting to the state. Exposure type, species, and submission date are at the discretion of the labs' respective form(s). Furthermore, some variables are not captured, such as termination specifics, quarantine time (if applicable), test ordering party (i.e., veterinarian, owner, etc.), date of result, and laboratory location.

The purpose of a public health surveillance system is to determine the need for public health intervention; assess the status of the disease; and supporting evidence for resource allocation, targeting at-risk locations, and educational gaps.[1] Currently, Kentucky's rabies data has limited epidemiological capabilities, and data issues prevent its use as a surveillance system. The lack of a methodical and systematic approach to collecting accounts of rabies events affects the ability to investigate and reduce unsatisfactory samples, validate laboratory reports, and limits veterinary accountability within state guidelines. Overall, the limitations in the current data system prevent effective public health surveillance. These issues are a limiting factor in rabies elimination, but a driving factor in over-testing, overtreatment, and overspending for the state of Kentucky.

Background

Introduction

Rabies is a deadly zoonotic disease from 15 recognized RNA viruses from the genus *Lyssavirus* of the family *Rhabdoviridae.*[2,3] Rabies exposure develops into an acute, viral infection, resulting in the attack of the central nervous system (CNS), multiplying in the brain of an infected host.[3] If a rabies infection remains untreated, and clinical signs of infection form, the outcome is always fatal.[2] All unvaccinated mammals are susceptible to the infection of the rabies virus.[1] Transmission of the rabies virus occurs from direct contact with the saliva from an infected (“rabid”) animal, either through scratch, bite, or licking of an open wound, although there are rare case reports of infection through aerosol inhalation and organ transplants.[3] For animals, confirmation of rabies infection is through direct fluorescent antibody (dFA) test of brain tissue, resulting in the euthanization of the animal.[5,6] There are no tests available that could diagnose a rabies infection before death (antemortem) for animals.[7] In humans, several laboratory tests of biological samples and post-exposure prophylaxis (PEP) are necessary to ensure complete recovery; including 4 doses of the rabies vaccine and human rabies immunoglobulin (HRIG).[7] However, a complete treatment of PEP for rabies costs around $3,800, not including hospital costs and wound care.

Global Epidemiology of Rabies

Even though rabies is a completely preventable disease through vaccination, there are an estimated 59,000 human deaths globally each year from canine rabies virus variants (RVVs) (>99% of human cases), with over 95% of rabies cases occurring in Africa and Asia.[7] Comparatively, financial estimates claim Africa spends the least amount of rabies PEP and have the highest cost of human mortality annually, whereas Asia spends USD$1.5 billion per year on rabies PEP, five times greater than the United States.[7] Furthermore, the country with the highest burden of rabies is India, accounting for over 35% of all human rabies deaths.[7] With improved access to rabies vaccination programs (to reduce canine rabies virus variants) and rabies PEP, a significant amount of human lives could be saved every year.

US Epidemiology of Rabies

For the United States, human rabies cases have been reduced substantially due to the elimination of canine RVV, the continued veterinary practice of rabies vaccination in pets and livestock, mass wildlife inoculation programs, and increased rabies education and awareness for veterinary practitioners, healthcare providers, and the lay public.[2,8] However, human exposure to rabies continues to occur, mainly from contact with bats and wildlife.[9] Wildlife species account for more than 90% of all rabies cases in the U.S., with the leading RVV reservoirs being bats (hematophagous and insectivorous bat RVVs), raccoons (raccoon RVV), striped skunks (south-central, north-central, and California RVV), and foxes (Arizona gray fox and arctic gray fox RVV)(see Figure 1).[2] Previous research has indicated that rabies virus transmission occurs mainly between members of the same species or the same geographical region, with the exception of bats.[10]

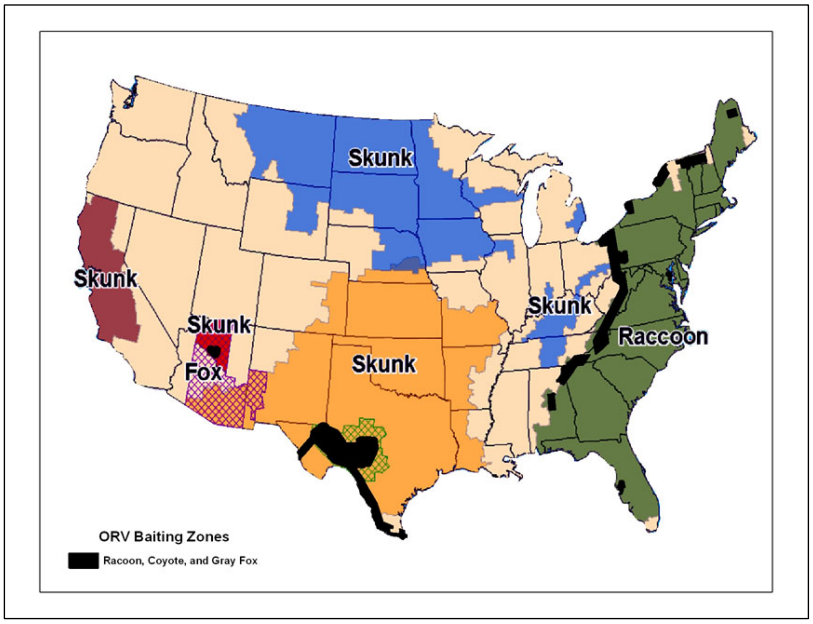


Figure 1. Primary rabies reservoir locations in the United States with targeted oral rabies vaccinations (ORV) baiting zones[24]

Kentucky Epidemiology of Rabies

For the Commonwealth of Kentucky, RVVs are still prevalent in the natural wildlife, with the state's rabies positivity rate continually estimated at 2.0%.[11] The natural, terrestrial reservoir for rabies in Kentucky is the striped skunk (*Mephitis mephitis*).[12] Additionally, bats (and the respective RVVs) function as another reservoir for the region. Furthermore, Kentucky's natural rabies reservoirs are threatened by encroaching raccoon rabies variants in the east. Kentucky's eastern border states have been targeted zones of the oral rabies vaccination (ORV) programs sponsored by the USDA as a mass inoculation effort to decrease exposures to rabies from raccoons among wildlife and humans (see Figure 1).[13] In addition to the vaccination efforts, Kentucky continues to be spared against an increase of raccoon RVVs due to the geographic barrier of the Appalachian Mountains.

The Kentucky Department of Public Health (KDPH) has a rabies program within the Department of Epidemiology which collects data on suspected cases of rabies infection of animals and prevention of rabies in humans. Additionally, the state works to address the needs of pre-and post-exposure prophylaxis in human exposures and works with wildlife authorities and veterinarians to continue education efforts on the topics related to rabies.[14]

Financial Burden of Rabies

Rabies is a costly disease when it comes to human vaccination and treatment. The estimated spending of United States rabies prevention, vaccination, and treatment is $300 million ($245 million - $510 million)[15]. The largest spending comes from the medical care related to post-exposure prophylaxis (PEP), with the United States giving 30,000 - 60,000 courses of PEP annually, estimated to cost $228 million.

For Kentucky, there is a rigid dichotomy between the costs of animal and human treatments. For animals, the price of rabies vaccination can vary between $10 to $20 for a single dose that lasts one year. Kentucky law designates that if an animal is vaccinated under a mass vaccination clinic by a local health department, the owner shall not pay more than $10 for each vaccination given (902 KAR 2:070; Section 8). Furthermore, if the animal is suspected of being rabid, the state will cover the cost for testing. However, for human treatments, the costs are extremely high due to the uncommon treatment and the short shelf life of human-approved rabies vaccinations and human rabies immunoglobin (HRIG). For humans, the rabies vaccine is a 3 dose regimen over a month with an out-of-pocket cost of $900 - $1,100. These treatments have continued to increase in price, with the top manufacturers of HRI increasing the sale price by 370-388% within the past decade.[16] In addition to the increase in treatment price, 95% of rabies post-exposure prophylaxis assessment and treatments happen in emergency departments, resulting in additional costs.[17] While insurance factors into the total costs of rabies PEP, the CDC continues to estimate that a full treatment of rabies PEP costs over $3,800. An estimated breakdown of rabies is seen in Table 1.

The estimated out-of-pocket cost for rabies PEP is $9,905 to $15,831. With a large out-of-pocket cost for rabies PEP, there is an urgent concern over treatment hesitancy after possible exposure and/or medical debt if treatment is sought after. Ultimately, the greatest concern is Kentuckians contemplating care avoidance for a disease that is 100% fatal if left untreated.

Table 1. Estimated Breakdown of Rabies Spending for Humans and Animals in Kentucky

Estimated Spending of Rabies in Kentucky	Estimated Cost
Animal	
Rabies testing	
dFA test	$0
Rabies Vaccine	$10 - $20 – Single dose (1 yr)
Human	
Vaccination	$900 - $1100 (3 – dose regimen)
Post exposure prophylaxis (PEP)[17-20]	
Human rabies immunoglobulin injection (HRIG)*	$3,612 per 10 ml (Imogam®) $3,550 (HyperRAB®)
Rabies vaccine	$1200 – $1400 (4-dose regimen)
Hospital (ER) care	$1,740 per visit†
Wound care	$3,415 - $3,859
TOTAL Out-of-pocket estimate	$9,905 - $15,831

** Estimated wholesale costs[17,18]*

† Rabies treatments can vary by number of visits (up to four visits for full treatment) and location of treatment[19,20]

Rabies Reporting in Kentucky

Rabies, for both human and animals, has been a nationally notifiable disease in the United States since 1944 (Appendix A). Rabies reporting for animal samples are conducted passively, resulting in the potentially rabid sample being submitted to one of the 130 state and national pathology laboratories in the United States. Kentucky's rabies laboratory testing protocol indicates that any animal should be submitted for testing if there is a known human exposure, the animal is exhibiting clinical signs of rabies in the CNS, and there is high clinical index of suspicion of rabies with the presentation of acute fulminant encephalitis.[10] The current process of rabies reporting in Kentucky is visualized in the flow diagram below (Figure 2).

For a suspected case of rabies, state law (KRS 258.085a) indicates that a veterinary health officer has the right to quarantine a suspected case no more than one hundred eighty (180) days any animal bitten by another animal known or suspected to have rabies; ten (10) days any dog, cat, or ferret which has bitten a human being; or ten (10) days any dog, cat, or ferret which exhibits symptoms of rabies. If no clinical signs of rabies begin to display in the animal, the animal is vaccinated and released to the owner with certification of vaccination.[21] If clinical signs of rabies form or there is a high clinical index of suspicion by a veterinary health officer, the animal is to be destroyed and tested for rabies. If a veterinary health officer decides to not quarantine the animal, the officer can order an animal to be destroyed and tested for rabies (KRS 258.085b).

If a wild or exotic animal has bitten a human or shows signs of rabies, it is to be terminated (KRS 258.085c). If an animal is to be terminated under the suspicion of rabies, KRS

258 states that the animal is to be killed in a manner that preserves the brain tissue and brain stem for testing (e.g., no shooting or clubbing to the head). When an animal is terminated under suspicion of rabies, the owner or the veterinary health officer is to submit the head of the animal to an approved laboratory for confirmatory testing.

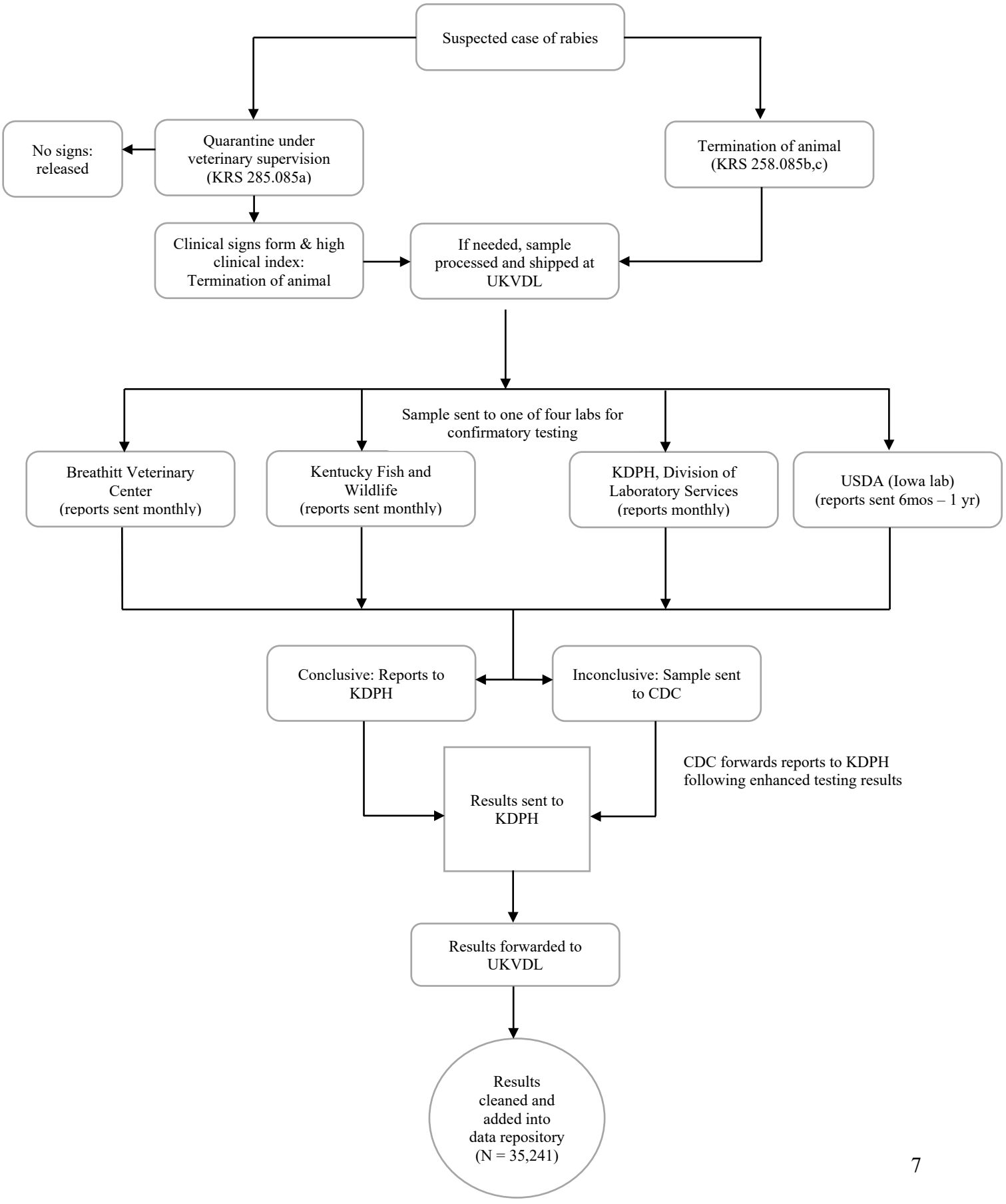
There are five approved laboratories performing dFA confirmatory tests for rabies in Kentucky:

- Kentucky Department of Public Health, Division of Laboratory Services (KDPH);
- Breathitt Veterinary Center (BVC);
- Kentucky Fish and Wildlife (KFW);
- United States Department of Agriculture (USDA); and if needed,
- Centers for Disease Control and Prevention (CDC).

Rabies results can be concluded within 24 – 72 hours from the start of testing.[8] Results can be labeled as "positive", "negative", "inconclusive/referred" or "unsatisfactory for testing" (due to "decomposition or extreme traumatic damage to the brain").[22] Results are sent to the KDPH on each laboratory's separate, unique reporting form monthly (BVC, KDPH, KFW) or bi-annually/annually (USDA). Cumulative reports are forwarded from KDPH to the University of Kentucky Veterinary Diagnostic Lab (UKVDL) at the start of every month. Reports are then examined, cleaned, and stored in a data repository at UKVDL. Furthermore, UKVDL uploads the new data into its "Animal Disease and Diagnostic Mapping" program, a publicly accessible online data visualization website, utilized by veterinarians, state and local officials, and agricultural workers.[23]

Currently, a data repository houses over 35,000 reports submitted since 1989. All information pertaining to samples are anonymous. Data contains species, submission date, laboratory test result, exposure type, county of origin, and state.

Figure 2. *Flow Chart of Rabies Data Collection Process in Kentucky*



Methods

Measures

Variables available for analysis are species, submission date, laboratory test result, exposure type, and county of origin. Rabies positivity rates were calculated from positive laboratory test result over total sample submissions for a given time period (all-time, yearly, etc.). Unsatisfactory rates were calculated from any laboratory test result reported as "Unsatisfactory for testing" or "Inconclusive" over the total number of samples submitted for testing. "All-time" refers to the entire 32 years of rabies data (1989 – 2020). "Over time" refers to five-year interval averages of rabies positivity.

Data Analysis

Samples are described by positivity rate (all-time positivity rates and by five-year time intervals for longitudinal rates) by species. Rabies positivity rates were also graphed over the years by month to account for seasonality. Data were also presented spatially in QGIS® to identify locational trends in positivity; counties were ranked by all-time positivity rates. Unsatisfactory rates are also described longitudinally, by species, and by county. Descriptive statistics were performed in R® version 4.0.2 and Microsoft Excel®. Supplemental graphs and figures are provided in the Appendix.

Results

From January 1st, 1989 through December 31st, 2020, a total of 35, 205 animal samples were submitted for rabies testing in Kentucky. The submitted samples varied over 55 different species of animals across all 120 counties in Kentucky. Samples (n = 6) were removed for being identified as birds (not rabies susceptible) for not originating from Kentucky counties (n = 20), resulting in a total of 35,179 samples.

Rabies All-Time Positivity

From the 35,179 samples, 837 (2.4%) were positive cases, 1,589 were unsatisfactory samples for testing (4.5%) and 32,753 (93.1%) were negative cases. All-time positivity rates (Table 1) were calculated by species classification, with skunks having the highest all-time positivity at 1.3% (n = 448). Skunk positivity rates were followed by all-time positivity rates in bats (0.59%, n = 208) and dogs (0.25%, n = 90). Graphical representations of rabies case counts and rabies positivity can be seen in Appendix B, Appendix C and Appendix D.

Table 1. Rabies Cases in All Species Across All Years (1989-2020)

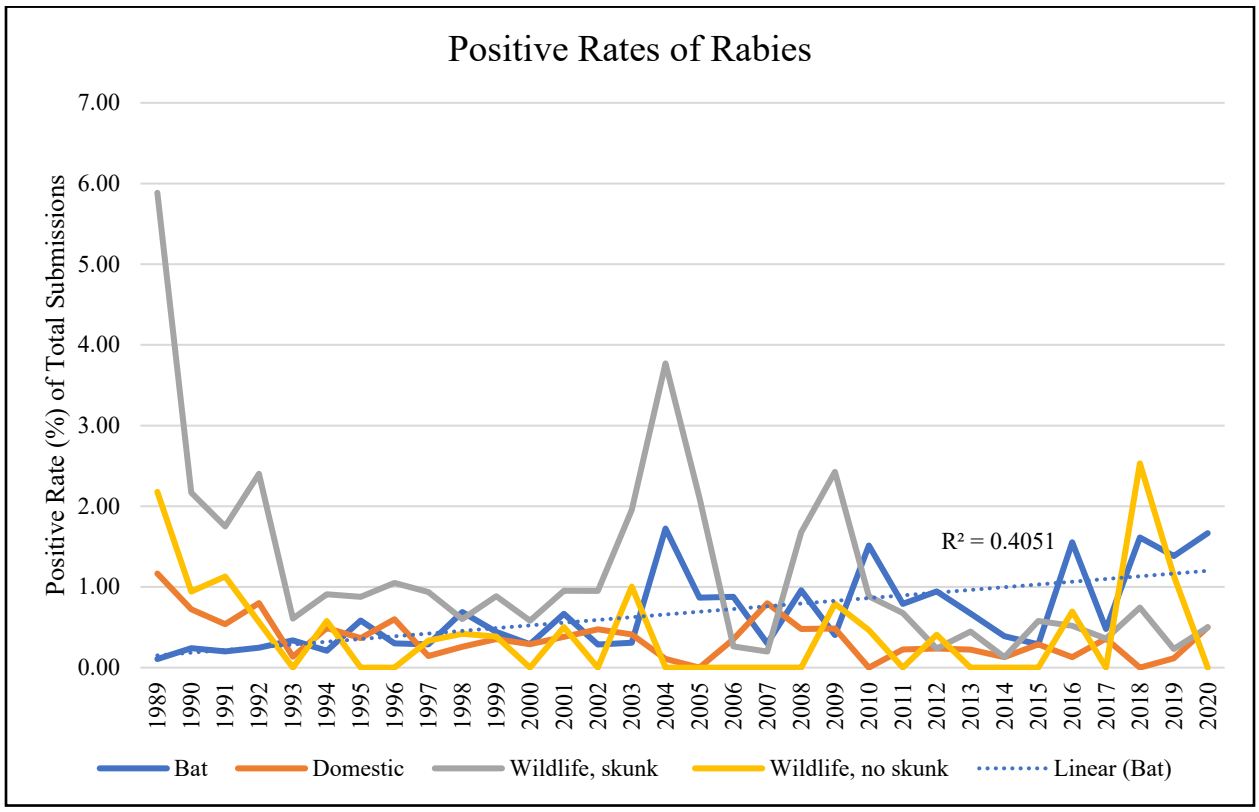
		Rabies Status	
		All-time Positive Cases	
Species	**N**	**n**	**%**
Domestic			
Cats	8833	6	0.017
Cattle	1244	22	0.062
Dogs	9728	90	0.256
Ferrets	121	0	-
Horses & Donkeys	1159	25	0.071
Sheep & Goats	215	1	0.003
Other[*]	245	0	-
Wildlife			
Fox	992	31	0.088
Opossum	444	0	-
Raccoons	3968	5	0.014
Rodents[+]	1104	1	0.003
Skunks	1226	448	1.273
Squirrels	712	0	-
Other[†]	801	0	-
Bat RVVs			
All species	4380	208	0.591
Unknown	7	0	-
Total	35,179	837	2,380

**Other domesticated and exotic animals: 13 alpacas, 1 camel, 3 chinchilla, 1 coatimundi, 18 gerbils, 12 guinea pigs, 142 hamsters, 2 hedgehogs, 1, kangaroo, 19 llama, 1 monkey, 24 pigs, 7 wolf hybrids, and 1 zebra.*
+ Rodents include: chipmunk, gopher, ground mole, marmot, mole, mouse, muskrat, prairie dog, rat, shrew, vole and woodchuck.
†Other wildlife includes: 1 badger, 10 beavers, 2 black bears, 89 bobcats, 371 coyotes, 28 deer, 33 elk, 1 marsupial, 31 mink, 2 mountain lion, 445 opossum, 7 otter, 209 rabbits, 10 weasels, and 8 wolves.

Longitudinal Positivity Rates

Skunk cases represented the highest positivity rates in 2002 – 2006 and 2007 – 2010, with the highest positivity rate in 2004. With the exclusion of skunks in the wildlife classification, the longitudinal positivity rate remains below 2.0%, except for a positive cluster in 2018. When considering species longitudinally, bat RVVs are increasing in positivity (R^2 = 0.41), while all other wildlife and domestic cases remain constant (Figure 3). Over time, there was an observed increase in positive cases during the months of April – September, with the highest peaks located in June, July, and August (Appendix E).

Figure 3. Positivity Rates by Species Classification across all years, 1989-2020



For all-time county positivity rates, there seem to be no geographical clustering that would indicate interspecies transmission. The county with the highest all-time rabies positivity rates is Simpson County, Kentucky (14.1%). A full list of the top 10 counties in Kentucky with the highest rates of positive cases can be found in Table 2.

Figure 4. Spatial distribution of all-time positivity in Kentucky counties, 1989 - 2020

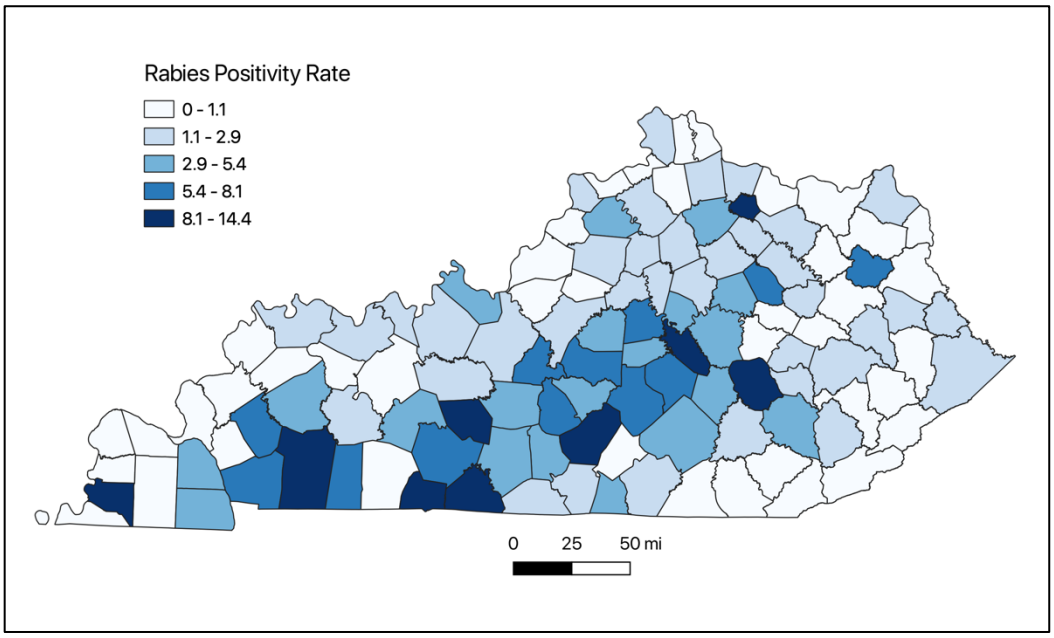


Table 2. Top Ten Kentucky Counties with Highest Positivity Rate

County Name	Positivity %
Simpson County	14.1%
Allen County	12.4%
Robertson County	11.7%
Edmondson County	10.8%
Adair County	10.7%
Hickman County	10.0%
Jackson County	9.4%
Garrard County	9.3%
Christian County	9.3%

Unsatisfactory Rates

Unsatisfactory testing rates have slightly decreased over time (Appendix C). All-time rates of unsatisfactory are reported at 5% compared to 2% positivity. By species, the all-time unsatisfactory rate is highest in dogs (26.5%), followed by cats (19.2%) and bats (18.9%). Longitudinally, unsatisfactory rates have an observed decline in the last decade for dogs and cats, while unsatisfactory rates for bats have slowly increased. More information pertaining to unsatisfactory rates by species can be seen in Appendix F.

For all-time county unsatisfactory for testing rates, there seem to be geographical clustering of high rates of unsatisfactory samples originating in the eastern region of the state (Figure 5). The lowest rates of unsatisfactory samples originate from central Kentucky. The county with the highest all-time unsatisfactory for testing sampling rates is Marshall County, Kentucky (16.7%). A full list of the top 10 counties in Kentucky with the highest rates of unsatisfactory for testing sample rates can be found in Table 3.

Figure 5. Spatial distribution of all-time unsatisfactory for testing rates in Kentucky counties, 1989 - 2020

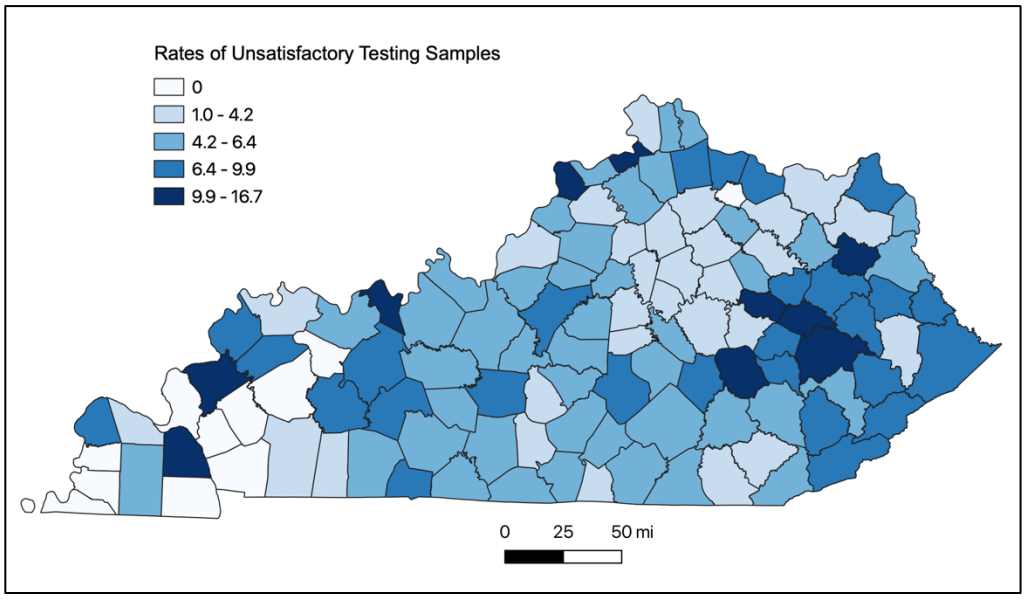


Table 3. Top Ten Kentucky Counties with Highest Unsatisfactory Rate

County Name	Unsatisfactory %
Marshall County	16.7%
Wolfe County	14.5%
Elliot County	14.3%
Gallatin County	13.6%
Hancock County	12.1%
Powell County	12.0%
Crittenden County	11.9%
Jackson County	11.2%
Breathitt County	11.1%
Trimble County	10.6%

Discussion

Kentucky's rabies reporting spans over 32 years of data collection. Overall, the number of rabies cases and rabies testing has remained constant throughout the decades. However, the number of bat rabies cases has increased within the past decade. Skunks continue to be the primary terrestrial reservoir for rabies. Dogs have the highest rates of unsatisfactory for testing in the state, followed by cats and bats; indicated by excessive brain decomposition or extreme trauma damage before testing. There have been cases of canine RVVs since the declaration of elimination in 2007; evidence suggests that cases of canine rabies in the United States result from wildlife exposure or imported from a country with endemic rabies.[25] There was noticeable clustering of high unsatisfactory for testing rates in eastern Kentucky – possibly linked to veterinary density[26] across the state (Appendix G), veterinary practitioner educational gaps, or issues with sample processing and delivery.

A recurring limitation to any rabies reporting is the lack of real-time surveillance[13]. For Kentucky, this is mainly from the delay in result submission from the five laboratories that can range from a month to 18 months. This delay can hinder the state's ability to track trends across counties and regions with immediacy. Furthermore, the use of unstandardized forms can result in additional data cleaning and recoding, adding delays up to two weeks and creating possible data entry errors. Unstandardized methods of data collection and reporting can also result in data incompleteness; affecting the data's quality and degree of usefulness. Additionally, the data is influential when addressing public health services and laboratory testing of suspected cases, directly guiding healthcare recommendations for rabies post-exposure prophylaxis in humans, so quality, usefulness, and timeliness are imperative.

Currently, Kentucky's rabies reporting has limited capabilities in comparison to that of a true public health surveillance system. The goal of a public health surveillance system is to be an ongoing, systematic collection of data with the intention of analysis and dissemination in the goal of prevention and control.[1] The current status of Kentucky's rabies data management is the existence of a database of suspected rabies event reporting, rather than rabies surveillance. The resulting outcome is limited epidemiological capabilities and data issues preventing use as a surveillance system. The lack of a methodical and systematic approach to collecting accounts of rabies events affects the ability to investigate and reduce unsatisfactory samples, validate laboratory reports, and limits veterinary accountability within state guidelines.

Recommendations and Improvements

Standardized Method of Data Collection

The main issue with the current methods of rabies data collection for Kentucky is the lack of universal reporting conditions to KDPH. A solution is to update the current methods to a standard reporting form for any lab that is testing and reporting to KDPH. Creating a universal form across all labs will ensure that any information collected is consistent across all variables, particularly exposure type and lab location. Furthermore, having a standard form will limit report incompleteness and increase the quality of the data that is being submitted for future analysis. This change is a simple and inexpensive solution that could be administered by the KDPH, in compliance with Kentucky rabies laws that allow additional standards related to public health.[21] Lastly, having a standard form could be the starting transition to an electronic, real-time reporting and surveillance system. This process could be similar to the system that was instated

by the CDC (in partnership with American Public Health Laboratories) to facilitate rabies reporting from laboratories, nationally.[2] However, this system has its limitations due to its capabilities to be more notifiable rather than analytical.

Electronic Case Report Form

If the system were to be implemented electronically, several issues could be addressed with the utilization of a standard, electronic case report form (eCRF). First, an eCRF can be located in a centralized online form where all parties involved can report on suspected cases in real-time. A real-time, online surveillance system can result in notification of suspected cases to responsible parties (e.g., local health departments, KDPH) in a sensitive and timely manner. An impactful solution embedded in an standardized eCRF is the automation of information transfers (i.e., from health officer to lab, to KDPH, to UKVDL) with the limited concern of user error, invalid responses, and consistency across all reports, in addition to audits of user logging and status reports. Furthermore, a centralized eCRF can "follow" the sample at every vital point of data collection in the reporting process (see schematic below). Lastly, data automation can result in active analysis and data dissemination with the use of external software packages in the online platform. Utilizing proper data collection tools can increase the quality and analyzability of Kentucky rabies data for future use(s).The recommended process for rabies reporting in Kentucky is visualized in the schematic below (Figure 6).

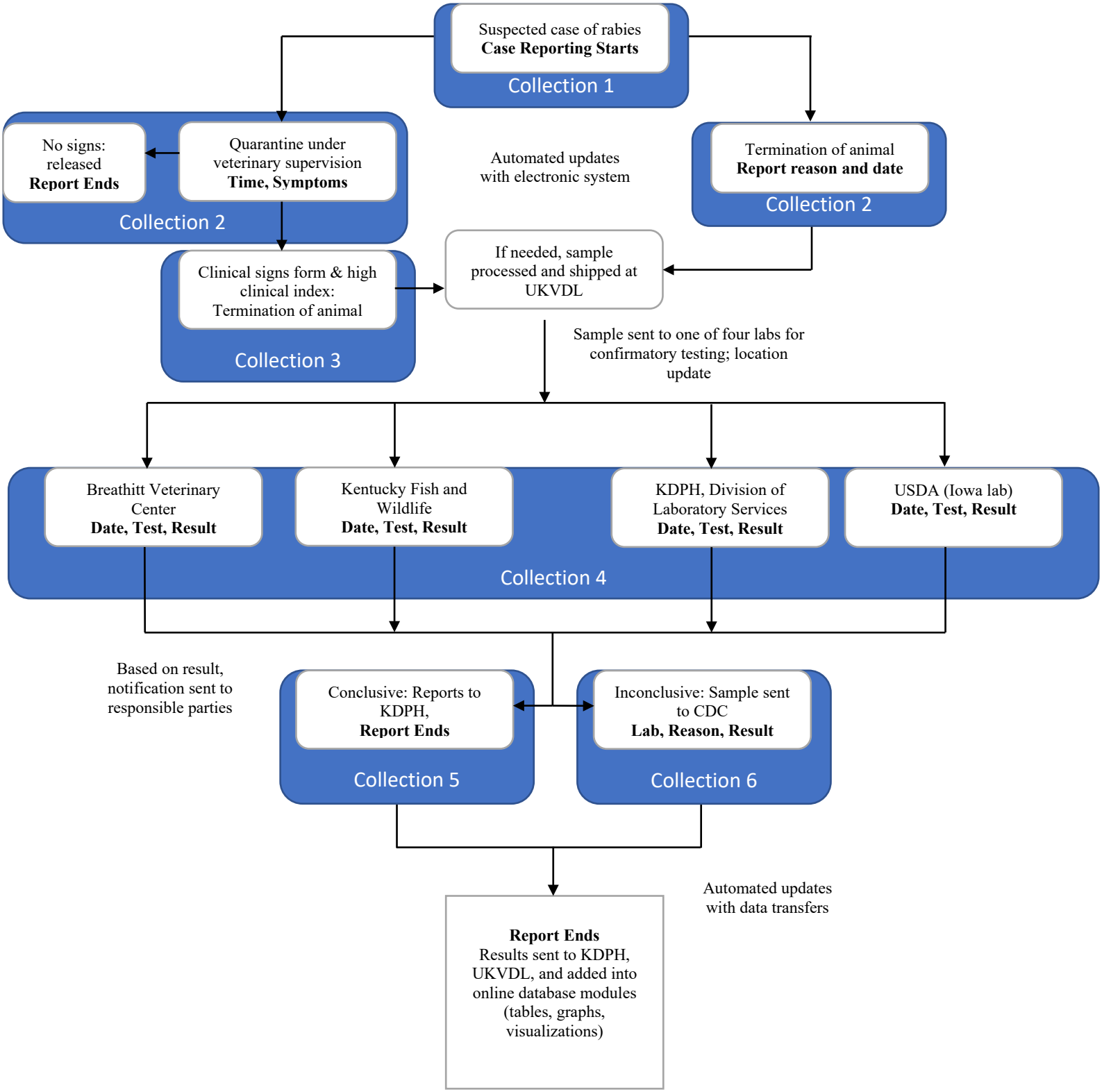
Process of Proposed Rabies Data Collection

If an electronic reporting system were to be implemented, data collection would start with any suspected case of rabies, rather than cases submitted for testing. Each new case would be assigned a universal KDPH case ID. Additionally, veterinary health officers would fill out standardized information of the suspected case: identified species, exposure types, location of exposure, county of origin, responsible party for submitting the animal, and, if applicable, the suspected start date of exposure. If a suspected case submitted for quarantine, information pertaining to quarantine time and clinical symptoms could be reported until release or termination. Furthermore, if an animal is terminated, information regarding termination reason and termination date could be collected.

If a sample is submitted for rabies testing, the electronic form could follow the sample to the designated lab. Labs would then fill out laboratory information such as laboratory name, date the sample was received, date the sample was tested, the sample test result, and specifics if the sample was reported unsatisfactory for testing. Ultimately, the goal of this process is to reduce the number of manual user data entries. Forms could automatically recode data to standard coding practices from character observations to numerical observations, resulting in improved data quality, validity and accountability. In addition to data quality, utilizing an eCRF would allow for a built-in notification system for positive rabies cases, notifying KDPH, the local health department of the originating county/region and the party involved with initial case reporting (e.g., veterinarian, health officer, etc.). Lastly, having a centralized, electronic case report form would allow for the automation of data transfers from the reporting party, to labs, to the KDPH.

Once a sample result was deemed "conclusive", the case form would close and the data is transferred to the KDPH and to UKVDL. Data can then be automatically uploaded to the UKVDL "Animal Disease and Diagnostic Mapping Initiative", allowing for rapid dissemination of rabies data for public use with greater efficiency.

Figure 6. Schematic of Data Collection Points for Rabies Surveillance



Public Health Impact

Zoonotic diseases have continued to rise in the past 100 years, with an estimation of 60% of emerging infectious diseases reported as zoonoses.[27] The main account for this is increased direct exposures to animals, increased human encroachment into the environment, and increased animal habitat loss. And rabies is no exception. The persistence of rabies in Kentucky, especially bat rabies virus variants, should concern public health officials. The most common source of human rabies exposure in the United States is from bats.[28] Previous research has indicated that rabies transmission from bats can be unrecognized due to minor punctures caused by bat bites.[28]

With a steady increase in Kentucky's bat rabies positivity, continued human encroachment into animal habitat, and increase in bat conservation efforts, the need for an active rabies surveillance system for the state is high. The result of rabies reemergence in urban settings, particularly in the case of bats, increases situations of possible human and domestic animal exposure; factoring into excessive human PEP costs and animal testing. Furthermore, there have not been any mass rabies vaccination campaigns for wild bats due to the difficulty of inoculation.[29] However, an effective surveillance system could supply supporting evidence for veterinary public health intervention should there be an increase in positive rabies clusters. Rabies control has been seen as the responsibility of veterinary health officers, but the integration of public health officials into the veterinary sector could increase the efforts of affected zoonotic disease control and prevention. Traditional methods of public and veterinary practitioner education, proper PEP, and rabies testing could be combined with an updated means of rabies surveillance and reporting in Kentucky to address the growing cases of rabies in bats.

Ultimately, the goal of having an updated surveillance system would support the grounds for innovative technologies for zoonotic disease surveillance. The increase of emerging and novel zoonotic diseases in animals and humans is increasing at an exponential rate. In the past 30 years, 30 new human pathogens have been detected, of which 75% were from animals.[27] Emerging zoonoses are a growing, global public health threat, and the methodologies for surveillance of zoonotic diseases need to be updated to match the rapid rate of emergence. Creating faster, effective, and responsive surveillance systems would result in the prevention of excessive disease burden in humans and animals. The implementation of an updated and innovative rabies surveillance system in Kentucky could be the foundation for a greater, national surveillance system for multiple zoonotic infectious diseases.

References

[1] Centers for Disease Control and Prevention (CDC). Introduction to Public Health. In: Public Health 101 Series. Atlanta, GA: U.S. Department of Health and Human Services, CDC; 2014. Available at: https://www.cdc.gov/training/publichealth101/surveillance.html.

[2] *What is Rabies? | Rabies | CDC*. (n.d.). Retrieved April 3, 2021, from https://www.cdc.gov/rabies/about.html

[3] Ma, X., Monroe, B. P., Cleaton, J. M., Orciari, L. A., Gigante, C. M., Kirby, J. D., Chipman, R. B., Fehlner-Gardiner, C., Cedillo, V. G., Petersen, B. W., Olson, V., & Wallace, R. M. (2020). Rabies surveillance in the United States during 2018. *Journal of the American Veterinary Medical Association*, *256*(2), 195–208. https://doi.org/10.2460/javma.256.2.195

[4] *Rabies - Brain, Spinal Cord, and Nerve Disorders - Merck Manuals Consumer Version*. (n.d.). Retrieved April 3, 2021, from https://www.merckmanuals.com/home/brain,-spinal-cord,-and-nerve-disorders/brain-infections/rabies

[5] *How is rabies transmitted? | Transmission | CDC*. (n.d.). Retrieved April 3, 2021, from https://www.cdc.gov/rabies/transmission/index.html

[6] *CDC - Diagnosis: Direct Fluorescent Antibody Test - Rabies*. (n.d.). Retrieved April 3, 2021, from https://www.cdc.gov/rabies/diagnosis/direct_fluorescent_antibody.html

[7] *WHO | Rabies.* Epidemiology and burden of disease. (n.d.). Retrieved April 27, 2021, from https://www.who.int/rabies/epidemiology/en/

[8] *CDC - Diagnosis: In Animals and Humans - Rabies*. (n.d.). Retrieved April 3, 2021, from https://www.cdc.gov/rabies/diagnosis/animals-humans.html

[9] Hampson, K., Coudeville, L., Lembo, T., Sambo, M., Kieffer, A., Attlan, M., Barrat, J., Blanton, J. D., Briggs, D. J., Cleaveland, S., Costa, P., Freuling, C. M., Hiby, E., Knopf, L., Leanes, F., Meslin, F. X., Metlin, A., Miranda, M. E., Müller, T., … Dushoff, J. (2015). Estimating the Global Burden of Endemic Canine Rabies. *PLoS Neglected Tropical Diseases*, *9*(4). https://doi.org/10.1371/journal.pntd.0003709

[10] Rupprecht, C. E., Freuling, C. M., Mani, R. S., Palacios, C., Sabeta, C. T., & Ward, M. (2020). A history of rabies—The foundation for global canine rabies elimination. In *Rabies* (pp. 1–42). Elsevier. https://doi.org/10.1016/b978-0-12-818705-0.00001-7

[11] Pieracci, E. G., Pearson, C. M., Wallace, R. M., Blanton, J. D., Whitehouse, E. R., Ma, X., Stauffer, K., Chipman, R. B., & Olson, V. (2019). Vital Signs: Trends in Human Rabies Deaths and Exposures — United States, 1938–2018. *MMWR. Morbidity and Mortality Weekly Report*, *68*(23), 524–528. https://doi.org/10.15585/mmwr.mm6823e1

[12] Wallace, R. M., Gilbert, A., Slate, D., Chipman, R., Singh, A., Wedd, C., & Blanton, J. D. (2014). Right place, wrong species: A 20-year review of rabies virus cross species transmission among terrestrial mammals in the United States. In *PLoS ONE* (Vol. 9, Issue 10). Public Library of Science. https://doi.org/10.1371/journal.pone.0107539

[13] Ma, X., Monroe, B. P., Cleaton, J. M., Orciari, L. A., Gigante, C. M., Kirby, J. D., Chipman, R. B., Fehlner-Gardiner, C., Cedillo, V. G., Petersen, B. W., Olson, V., & Wallace, R. M. (2020). Rabies surveillance in the United States during 2018. *Journal of the American Veterinary Medical Association*, *256*(2), 195–208. https://doi.org/10.2460/javma.256.2.195

[14] *Wildlife Reservoirs for Rabies | Exposure | Rabies | CDC*. (n.d.). Retrieved April 3, 2021, from https://www.cdc.gov/rabies/exposure/animals/wildlife_reservoirs.html

[15] *CDC - Cost of Rabies Prevention - Rabies*. (n.d.). Retrieved April 27, 2021, from https://www.cdc.gov/rabies/location/usa/cost.html

[16] *The High Cost of Surviving Rabies*. (n.d.). Retrieved April 27, 2021, from https://www.webmd.com/a-to-z-guides/news/20180220/the-high-cost-of-surviving-rabies

[17] *Why a simple, lifesaving rabies shot can cost $10,000 in America - Vox*. (n.d.). Retrieved April 27, 2021, from https://www.vox.com/policy-and-politics/2018/2/7/16851134/rabies-treament-expensive-emergency-room

[18] Pieracci, E. G., Pearson, C. M., Wallace, R. M., Blanton, J. D., Whitehouse, E. R., Ma, X., Stauffer, K., Chipman, R. B., & Olson, V. (2019). Vital Signs: Trends in Human Rabies Deaths and Exposures — United States, 1938–2018 . *MMWR. Morbidity and Mortality Weekly Report*, *68*(23), 524–528. https://doi.org/10.15585/mmwr.mm6823e1

[19] *The most expensive states for ER visits, ranked - CBS News*. (n.d.). Retrieved April 27, 2021, from https://www.cbsnews.com/pictures/emergency-room-visit-cost-most-expensive-states/30/

[20] *Chronic Wounds: Economic Impact & Costs to Medicare | Alliance of Wound Care Stakeholders*. (n.d.). Retrieved April 27, 2021, from https://www.woundcarestakeholders.org/news/studies-and-publications/chronic-wounds-economic-impact-costs-to-medicare

[21] *Kentucky Animal Control Laws · Kentucky Animal Care and Control Association*. (n.d.). Retrieved April 27, 2021, from http://kacca.org/portfolio-item/kentucky-animal-control-laws/

[22] Auslander, M. (2005). Rabies in Kentucky-2004 (Vol. 40).

[23] *Rabies Map*. (n.d.). Retrieved April 27, 2021, from http://vdl.uky.edu/EpidemiologyInformation/RabiesMap.aspx

[24] *USDA APHIS | Oral Rabies Vaccination*. (n.d.). Retrieved April 3, 2021, from https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/programs/nrmp/ct_orv_vaccination

[25] McQuiston, J. H, Wilson, T, Harris, S, Bacon, R. M, Shapiro, S, Trevino, I, Sinclair, J, Galland, G, and Marano, N. "Importation of Dogs into the United States: Risks from Rabies and Other Zoonotic Diseases." Zoonoses and Public Health 55.8-10 (2008): 421-26. Web.

[26] *2015 STATE OF ANIMAL HEALTH IN APPALACHIA REPORT*. (2015). https://www.lmunet.edu/college-of-veterinary-medicine/research/center-for-animal-and-human-health-in-appalachia/images/Full Report - State of Animal Health in Appalachia FINAL.pdf

[27] Jones KE, Patel N, Levy M, et al. Global trends in emerging infectious diseases. Nature 2008; 451:990-94

[28] *CDC - Bats - Rabies*. (n.d.). Retrieved May 12, 2021, from https://www.cdc.gov/rabies/exposure/animals/bats.html

[29] Stading, B., Ellison, J. A., Carson, W. C., Satheshkumar, P. S., Rocke, T. E., & Osorio, J. E. (2017). Protection of bats (Eptesicus fuscus) against rabies following topical or oronasal exposure to a recombinant raccoon poxvirus vaccine. *PLoS Neglected Tropical Diseases*, *11*(10), e0005958. https://doi.org/10.1371/journal.pntd.0005958

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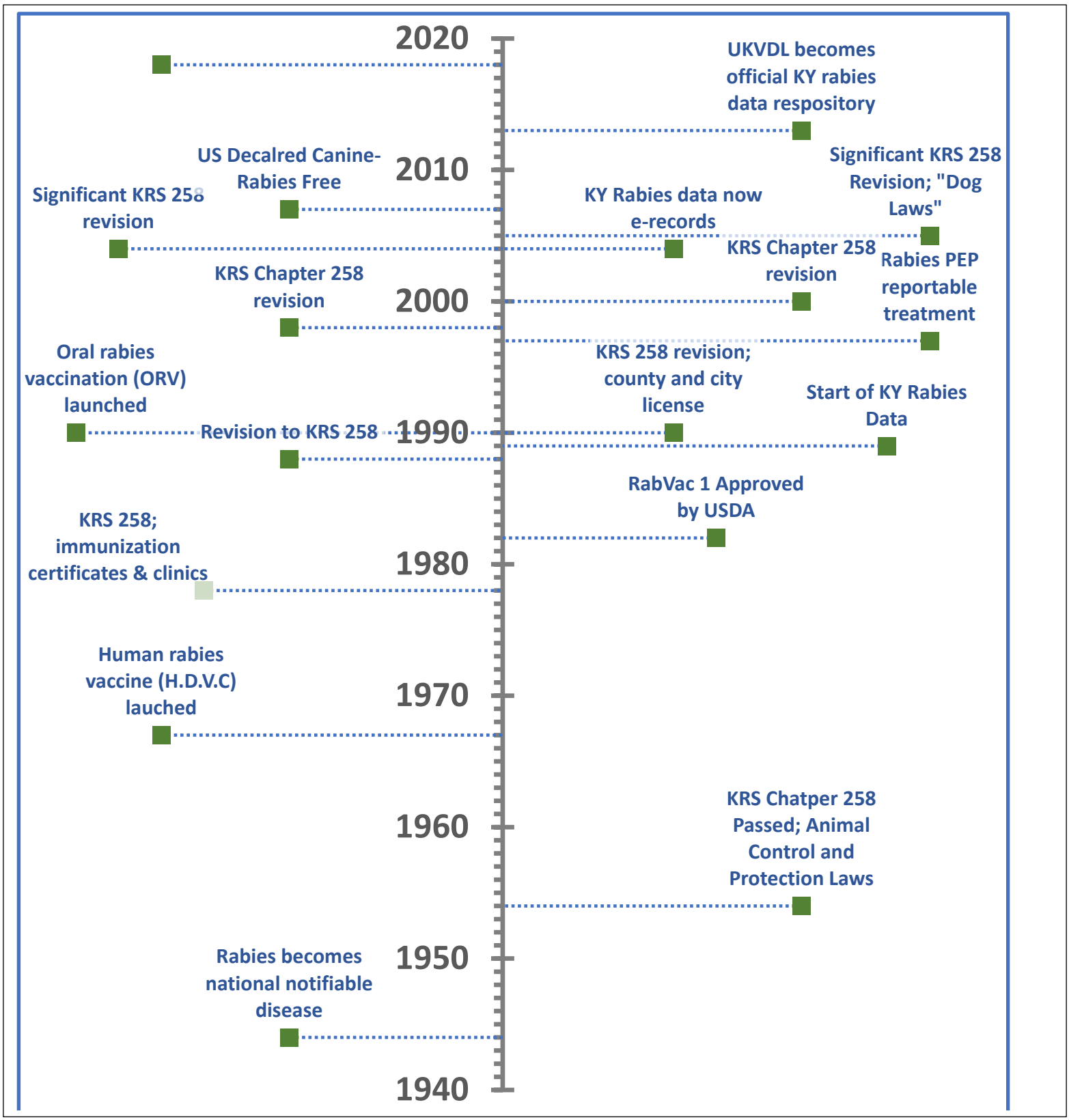
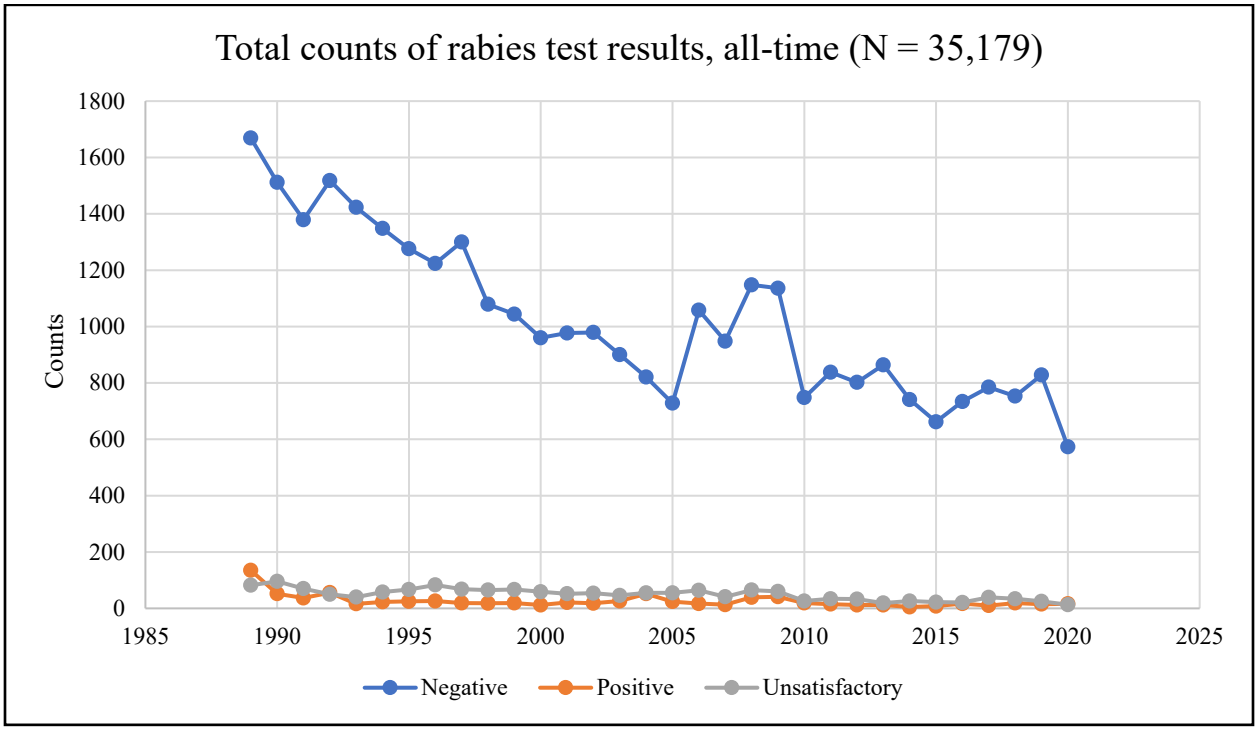
Appendix

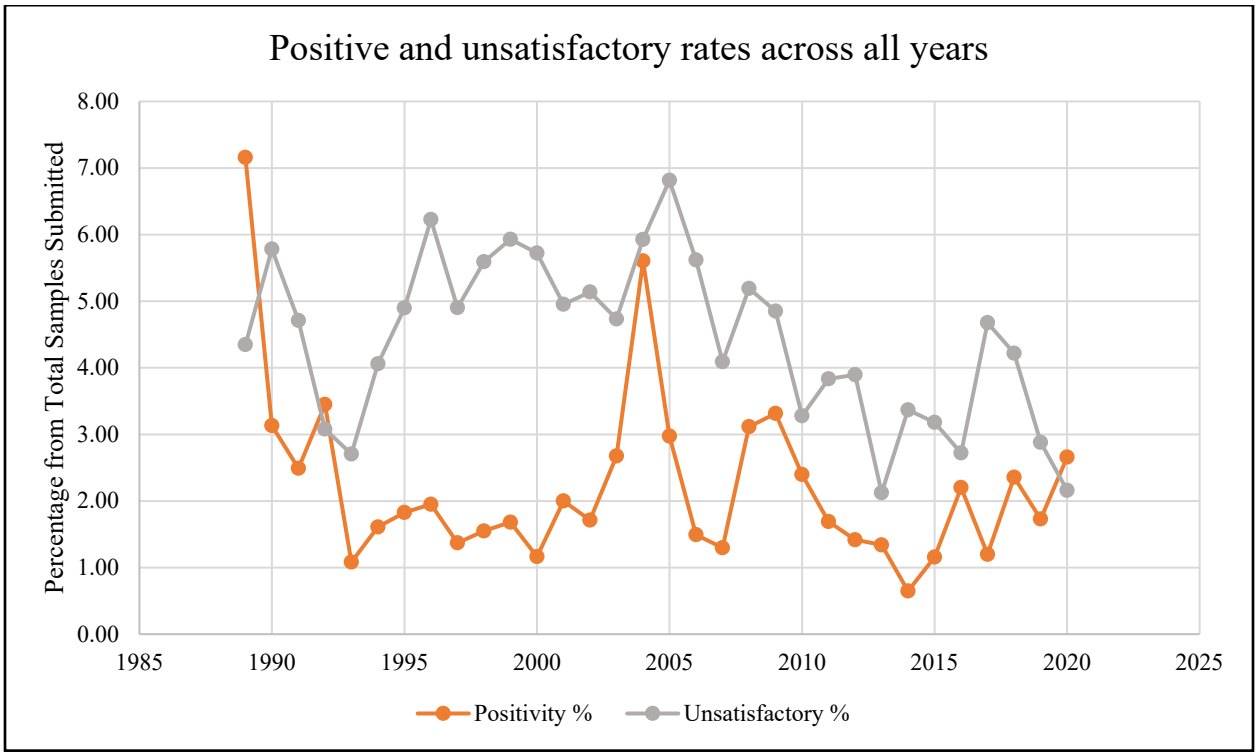
Appendix A: Timeline of Rabies Events in Kentucky



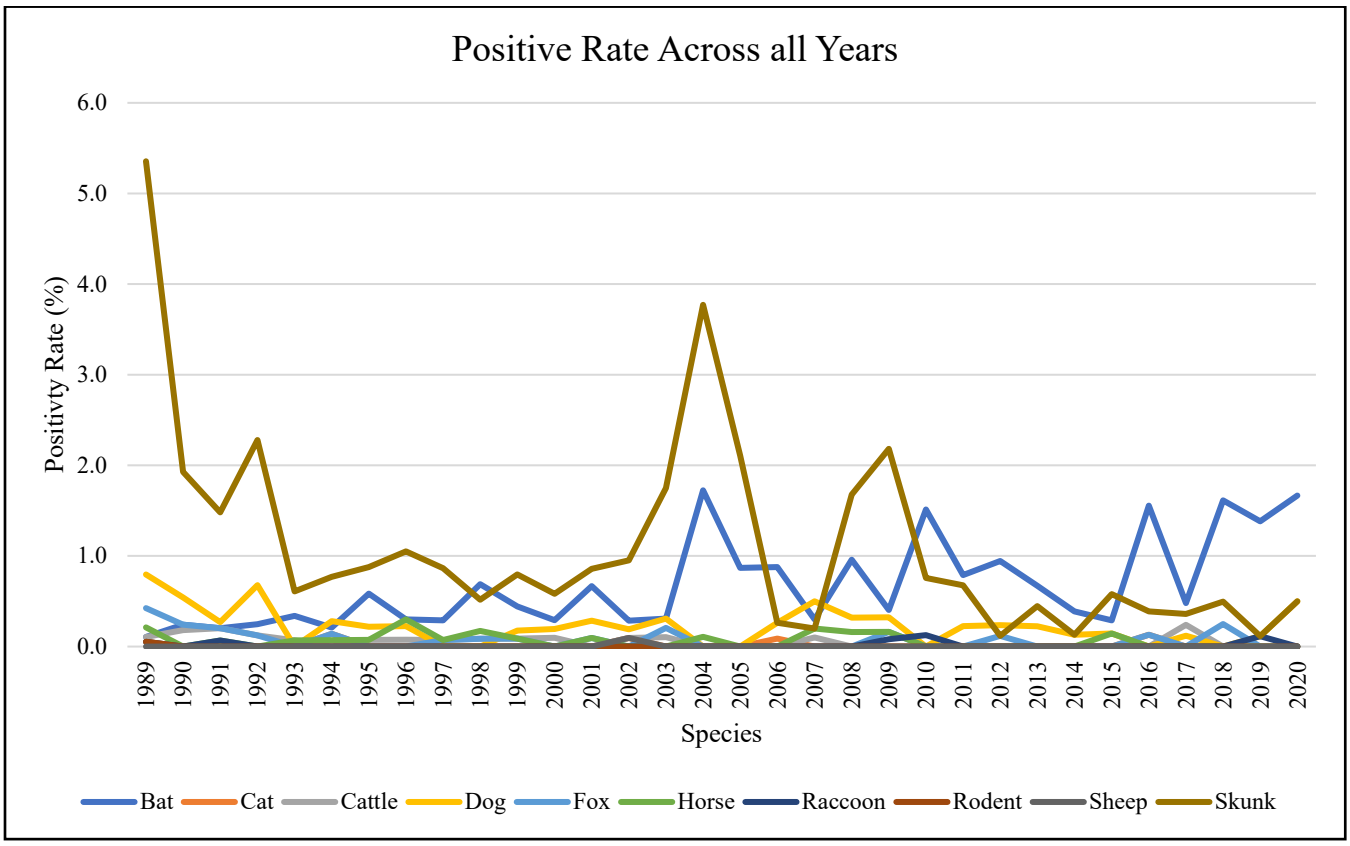
Appendix B: Reported counts of rabies test results, 1989 – 2020



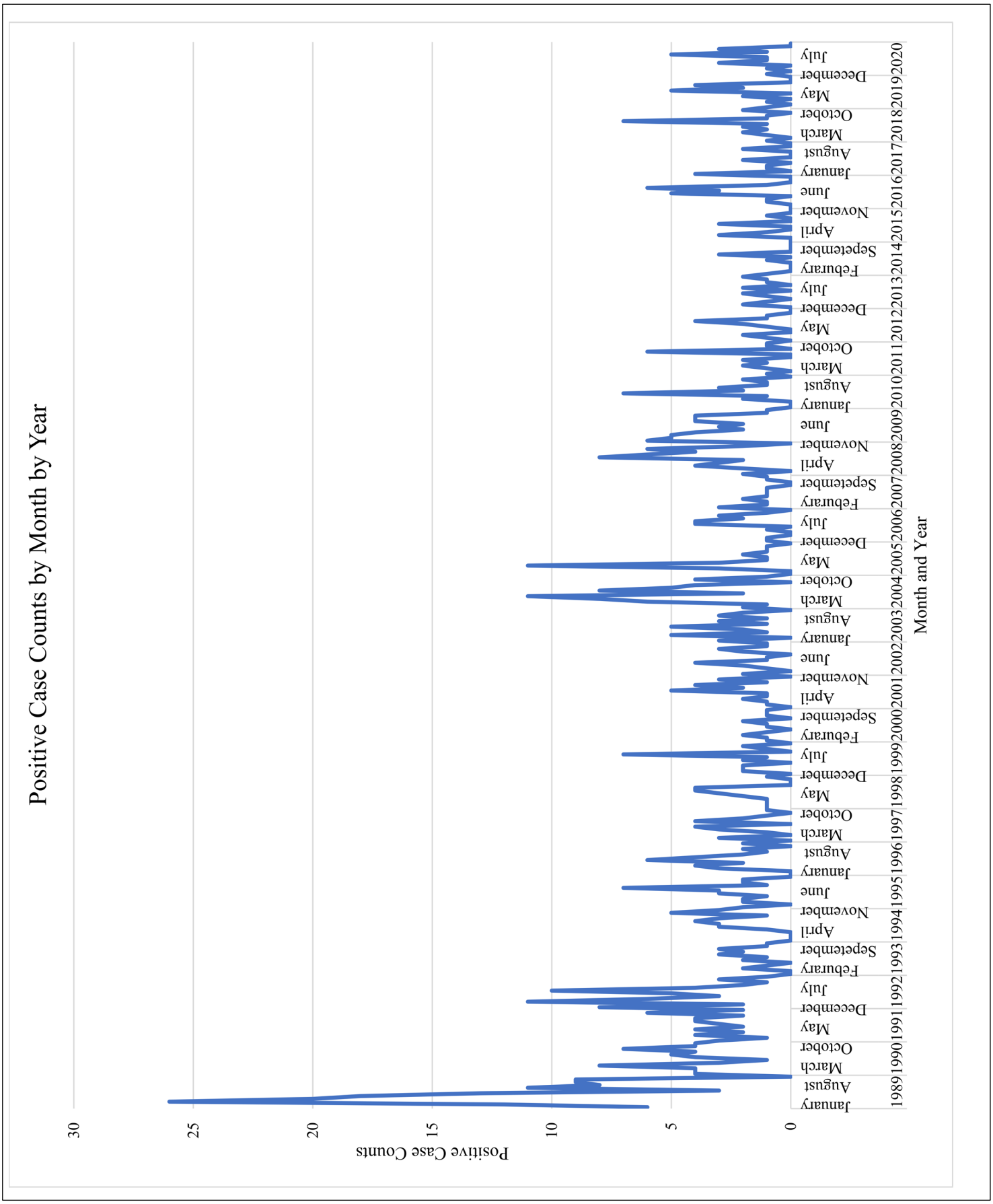
Appendix C: Percentage of "positive" and "unsatisfactory for testing" results, 1989 – 2020



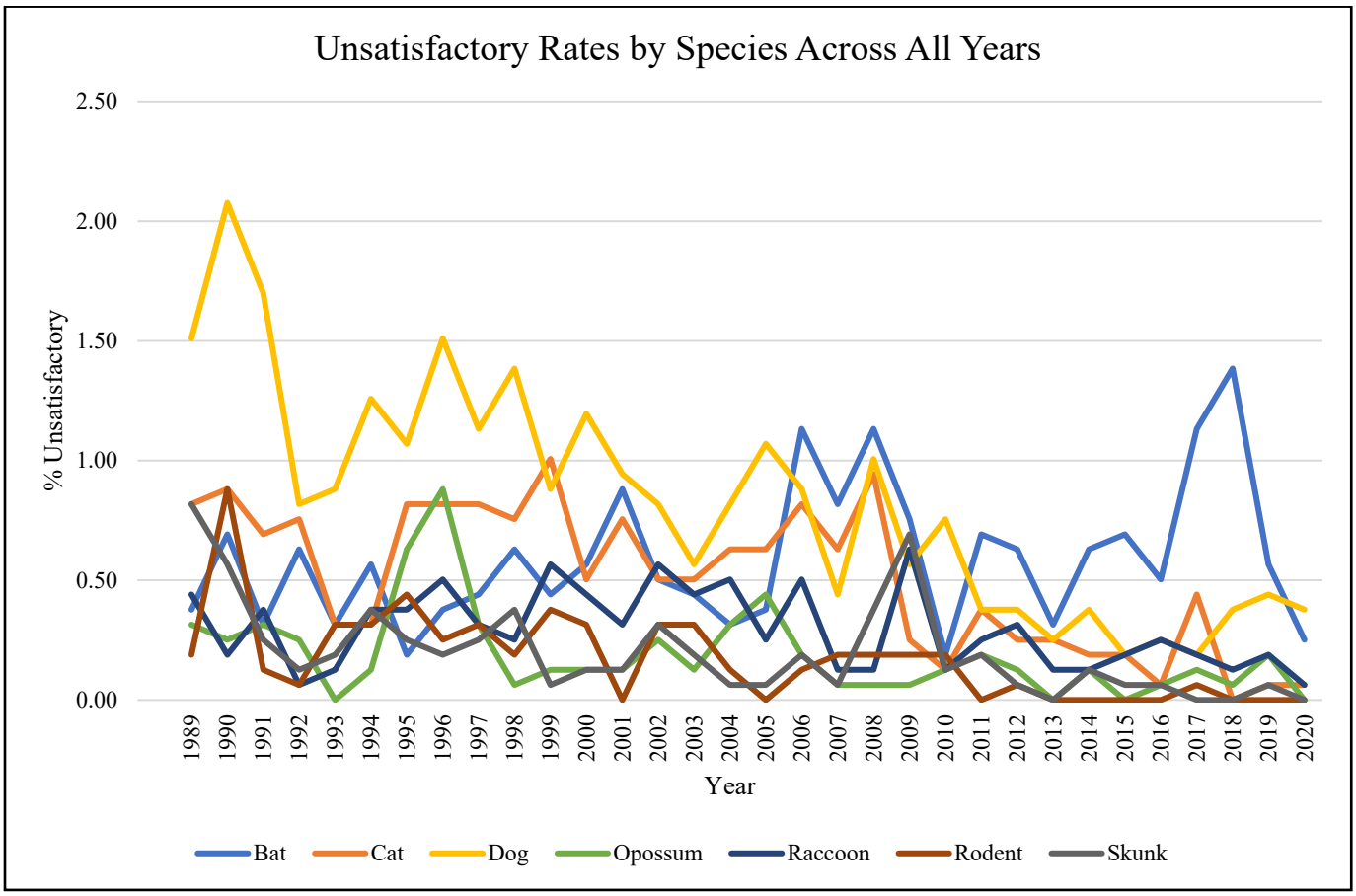
Appendix D: Rates of positivity by species classification, 1989 – 2020



Appendix E: Seasonality of Rabies Case Counts, January 1989 – December 2020



Appendix F: Unsatisfactory rates by species classification across all years, 1989 - 2020



Appendix G: Spatial distribution of veterinary density in Kentucky, CAHA, 2015 [25]